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Time series GHG emission estimates for residential, commercial, agriculture and fisheries sectors in India

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ABSTRACT

Green House Gas (GHG) emissions are the major cause of global warming and climate change. Carbon dioxide (CO_2) is the main GHG emitted through human activities, at the household level, by burning fuels for cooking and lighting. As per the 2006 methodology of the Inter-governmental Panel on Climate Change (IPCC), the energy sector is divided into various sectors like electricity generation, transport, fugitive, 'other' sectors, etc. The 'other' sectors under energy include residential, commercial, agriculture and fisheries. Time series GHG emission estimates were prepared for the residential, commercial, agriculture and fisheries sectors in India, for the time period 2005 to 2014, to understand the historical emission changes in 'other' sector. Sectoral activity data, with respect to fuel consumption, were collected from various ministry reports like Indian Petroleum and Natural Gas Statistics, Energy Statistics, etc. The default emission factor(s) from IPCC 2006 were used to calculate the emissions for each activity and sector-wise CO_2, CH_4, N_2O and CO_2e emissions were compiled. It was observed that the residential sector generates the highest GHG emissions, followed by the agriculture/fisheries and commercial sector. In the residential sector, LPG, kerosene, and fuelwood are the major contributors of emissions, whereas diesel is the main contributor to the commercial, agriculture and fisheries sectors. CO_2e emissions have been observed to rise at a cumulative annual growth rate of 0.6%, 9.11%, 7.94% and 5.26% for the residential, commercial, agriculture and fisheries sectors, respectively. In addition to the above, a comparative study of the sectoral inventories from the national inventories, published by Ministry of Environment, Forest and Climate Change, for 2007 and 2010 was also performed.

1. Introduction

Green House Gases (GHGs) from anthropogenic activities are the major driver for climate change. Increase in GHGs produces a warming effect on the environment, which leads to melting of glaciers, sea level rise, increased frequency of droughts and hurricanes and several other effects (Wang et al., 1976). To deal with GHG emissions mitigation and adaption, United Nations Framework Convention on Climate Change (UNFCCC) built the Paris Agreement in November 2015. It stresses on the imperativeness of climate action to limit global average temperature rise to 2 °C above pre-industrial levels. In addition, it also urges countries to try and limit this to 1.5 °C in order to reduce the impact of climate change and its associated risks. As on October 2017, 169 parties have ratified the agreement and India is one among them (UNFCCC, 2017).

India is not only one of the top ten leading economies in the world (The World Bank, 2016a), but is also one of the top five GHG emitters (WRI, 2014). However, India's GHG emissions are lower than the world average emissions per Gross Domestic Product (GDP). According to World Resources Institute, the world average energy emissions per GDP is 372 tCO_2e per Million $GDP, whereas India emits about 350 tCO_2e per Million $GDP (WRI, 2014).

India having a per capita GDP of 1582 $ per year, is also on the path of rapid economic development (The World Bank, 2016b). Increasing per capita GDP will inevitably lead to higher energy usage. This will, in turn, lead to higher emissions. In order to reduce GHG emissions, policymakers have adopted various low carbon strategies. For instance, as part of the Paris agreement, India has committed to UNFCCC to reduce the emissions intensity of its GDP by 33–35% from 2005 levels by 2030 (MoEFCC, 2015a). But, before implementing mitigation strategies, it is important to know the sources of GHG emissions (Ramachandra et al., 2015). By developing GHG inventories the source of emissions can be identified and the performance of a country in terms of GHG emissions can be evaluated.

India's energy sector contributed 56% and 54% of total emissions (excluding Land Use Land Use Change & Forestry) in 2007 and 2010,

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Abbreviations

ALGAS	Asia Least-cost Greenhouse Gas Abatement Strategy
BUR	Biennial Update Report
CAGR	Compounded Annual Growth Rate
CH_4	Methane
CO_2	Carbon dioxide
DG	Diesel Generators
EF	Emission Factor
GDP	Gross Domestic Product
GHG	Green House Gas
GWP	Global Warming Potential
HSDO	High Speed Diesel Oil
INCCA	Indian Network for Climate Change Assessment
IPCC	Inter-governmental Panel for Climate Change
Kg	Kilogram
Kt	Kiloton
kW	Kio watt
LPG	Liquefied Petroleum Gas
LSHS	Low Sulphur Heavy Stock
m^2	Square meter
MoEFCC	Ministry of Environment, Forest and Climate Change
$MtCO_2e$	Million tonnes of carbon dioxide equivalents
N_2O	Nitrous oxide
NCV	Net Calorific Value
NDC	Nationally Determined Contributions
NSS	National Sample Survey
PNG	Piped Natural Gas
Ppb	Parts per billion
tCO_2e	tonnes of carbon dioxide equivalents
TJ	Tera Joule
UNFCCC	United Nations Framework Convention on Climate Change
US	The United States
W	Watt

respectively (MoEF, 2010a,b; MoEFCC, 2015b). The 2006 methodology for the Inter-governmental Panel for Climate Change's (IPCC) divides energy emissions into four broad sectors: Electricity Generation, Transport, Other Sectors and Fugitive Emissions. The ‘Other Sectors’ include residential, commercial, agriculture and fisheries sectors. Though the contribution of emissions from these sectors is around 10% of the energy emissions, it is very important to quantify the sources of these emissions. Emissions from residential and commercial sectors are mainly driven by population growth and urbanization.

According to the Census of India 2011, about 377 million people comprising 31.14% of the country's population lived in urban India (Chandramouli, 2011a); which is projected to grow to about 600 million (40%) by 2031 and 850 million (50%) by 2051 (Government of India, 2016). The emissions from the cooking sector are expected to increase by 24% from 2012 to 2047 in an unchanging usage of cooking fuel and technologies scenario (NITI Aayog, 2015). Therefore, these sectors are of critical importance for identifying and implementing mitigation options. Rapid urbanization is expected to lead to a change in the pattern of fuel usage in the residential and commercial sector which could reduce the emissions from fuel usage if focussed policy interventions are enabled. The reduced growth rate of GHG emissions, over the years, is attainable by the adoption of clean and efficient cooking fuel options and cooking technology. Similarly, the emissions caused by the energy usage in agriculture and fisheries sectors will have a reduced growth rate due to the usage of energy-efficient agricultural implements.

This paper looks into the GHG emissions contributed by ‘Other sectors’ in India. Time series emission estimates from 2005 to 2014 was developed for the energy usage in the residential, commercial, agriculture and fisheries sectors. The base year was chosen as 2005 as this is the base year at which India's Nationally Determined Contributions (NDC) will be evaluated (MoEFCC, 2015a). Section 2 provides an overview of the existing GHG inventories in India. Section 3 provides the methodology used to calculate the time series GHG emission estimates for the other sectors. Lastly, Section 4 presents a discussion of the results and a comparative analysis of 2007 and 2010 emission estimates, performed with the national inventory database.

2. Background

2.1. India's national GHG inventory for 1990

The first GHG emission inventory for India was prepared by Mitra for the base year 1990 (Mitra, 1991; Mitra, 1992). The inventory considered the CO_2 and CH_4 gases for sectors like fossil fuel, rice, livestock, transport and coal mines. A more comprehensive 1990 inventory was conducted under the ALGAS (Asia Least-cost Greenhouse Gas Abatement Strategy) project in 1998 by considering the sectors and gases that were not considered in the initial analysis. The report prepared decadal projections of GHG emissions from 1990 to 2020. The inventory for the energy sector calculated the emissions from fuel combustion in energy industries and fugitive emissions from fuel. Detailed analyses on the fuel combustion in sectors like residential, commercial and agriculture/fisheries were, however, not conducted in this study.

2.2. Inventories of Ministry of Environment, Forest and Climate Change (MoEFCC)

In 2004, MoEFCC published the Initial National Communication to the UNFCCC with a detailed GHG inventory of various sectors for the base year 1994 (MoEFCC, 2004). A bottom-up inventory for CO_2, CH_4, and N_2O was prepared for different sectors. The report followed the 1996 guidelines of IPCC, with the usage of default emission factors. The GHG emissions from the residential and commercial/institutional sectors were part of this report. The reporting structure considered in this study was different from the 2006 IPCC methodology. For example, the energy utilised in the agriculture sector, like the diesel consumption of tractors and agricultural implements were considered under the transport sector, whereas the emissions from marine fishing fleets were not included in the inventory.

‘India: Greenhouse Gas Emissions 2007’ and ‘India's First Biennial Update Report to United Nations Framework Convention on Climate Change’ were published by MoEFCC in 2010 and 2015 for the detailed GHG inventories of 2007 and 2010, respectively (MoEF, 2010a; MoEFCC, 2015b). These reports separated the energy used in tractors, agricultural implements, pump sets, etc., from the transport sector and included them under the energy sector. In addition, GHG emissions from the fisheries sector were included in the 2007 and 2010 inventories. However, the emission calculations for the residential, commercial and agriculture/fisheries sectors are not transparent due to gaps in activity data and non-availability of reliable data. Due to lack of data, the emissions from captive power generation like Diesel Generators (DG) were not accounted for in the inventory. The report used the emission factors from revised 1996 IPCC and the 2006 guidelines for preparing the inventory and the sectoral fuel consumption data was taken from the respective ministry reports.

2.3. Inventory for marine fishing boats in 2010

Vivekanandan et al. compiled a CO_2 inventory for the carbon footprint of marine fishing boats in India for the years 1961, 1975, 1980, 1998, 2005 and 2010 (Vivekanandan et al., 2013). The inventory

looked at a comparative analysis of the CO_2 emission of different types of fishing crafts (mechanised, motorised and non-mechanised), at varying time periods of fisheries development in India. A primary survey data of diesel consumption of fishing boats were collected for 2005 and 2010, while a secondary data analysis was conducted to calculate the diesel consumption in 1961, 1975, 1980 and 1998. The emission factor defined by the US EIA (Energy Information Administration) for diesel was used to calculate the CO_2 emissions from the consumption of diesel in fishing crafts. The study did not analyse the emissions generated from the use of kerosene in fishing crafts.

The MoEFCC's inventories gave an absolute value for the GHG emissions in the residential, commercial and agriculture/fisheries sectors in India. The activity data for the emission estimation were sourced from published reports of government ministries and agencies andwere prepared by a group of government institutions and premier research development institutions in India. However, the emissions were observed to fluctuate highly between the years 1994 and 2010, as shown in Table 1. With the annual increase in population rate and the slow transition towards fuel-efficient technologies, the emissions are expected to increase. However, the inventory of 2010 shows that the emissions in the residential and agriculture/fisheries sectors have reduced drastically from 2007. Similarly, the GHG emissions from the commercial sector in 2007 have reduced largely compared to the 1994 inventory. The significant differences in these inventories might be due to inconsistent methodology used and lack of sectoral level data, as defined by IPCC, for the inventory preparation. Hence, there is a need for creating an inventory with a consistent methodology with data used from a common reliable source.

3. Methodology

The 2006 IPCC methodology was used for estimating the GHG emissions from combustion of various types of fossil fuels in the energy-related activities of the residential, commercial, agriculture and fisheries sectors. Bottom-up GHG emission estimates were compiled for CO_2, CH_4, and N_2O as per the activity data. The critical factors determining the quality and reliability of GHG inventory is directly dependent on the type of activity data and emission factor used. The basic equation used in this report for calculating the GHG emissions is shown in Equation (1).

$$Emissions_{GAS} = Activity\ data * Emission\ factor_{GAS} \tag{1}$$

In the energy sector, the activity data refers to the amount of fuel combusted in terms of TJ and the emission factor of the gas is expressed in t/TJ. The emission estimates will be expressed in tonnes of carbon dioxide equivalents (tCO_2e) by converting each GHG to CO_2e by multiplying with the respective Global Warming Potential (GWP). The GWP, as per the Second Assessment Report (AR2), over a time horizon of 100 years was considered for the conversion (Houghton, 1996; Solomon et al., 2007), as shown in Table 2. Most of the reports published by Government of India reports the data in the financial year (April to March). To report the emissions in the calendar year, activity data were apportioned by taking the weighted average of three-fourths of the preceding year and one-fourth of the succeeding year.

3.1. Activity data

The fuel consumption data are mostly reported in mass or volumetric unit. This is multiplied by the Net Calorific Value (NCV) of the fuel to express it in terms of TJ. Table 3shows the NCV used for each fuel type.

Activity data for the residential sector: Energy usage in the residential sector is mostly due to activities like cooking, heating and lighting. Based on the purchasing capacity of the people in India, the types of fuel used in households vary from coal, charcoal, fuelwood to Liquefied Petroleum Gas (LPG) and Piped Natural Gas (PNG). According to the Census of India 2011, 66% of the households in the country depend on firewood, crop residues and cow dung as fuel for cooking. 85% of these households are in rural areas. Only 28.5% of the country's households use cleaner fuels like LPG and PNG, of which 65% are urban households (Chandramouli, 2011b). However, in 2011, there had been an increase of 11% in LPG consumption in Indian households as compared to 2001 levels (Murthy and D'Sa, 2004). In addition, the sector uses diesel in DGs for their activities. India has a power deficit of around 9% which is assumed to be met by the people using diesel-based generators. DG sets of capacity less than 75 kW are assumed to be used in the residential sector based on discussion with sectoral experts. This was further validated from information provided in peer-reviewed reports (ICF International, 2014).

Activity data for commercial sector: Commercial sector includes office buildings, restaurants, convention halls, etc. The energy usage in this sector includes LPG, kerosene and natural gas for lighting and cooking and diesel used in DG sets. DG sets of capacity between 75 and 800 kW are assumed to be used in the commercial sector based on information in peer-reviewed reports (ICF International, 2014) and from sectoral experts.

Activity data for energy use in agriculture and fisheries sectors: The major energy usage in the agriculture sector is in the form of diesel used in tractors, agricultural implements and in irrigation pump-sets. Farmers in rural areas still depend on diesel-powered irrigation pumps due to limited access to electricity. According to the All India Study on Sectoral Demand of Diesel and Petrol (Nielson, 2013), about 13% of the diesel in the country was consumed by tractors, agriculture pump-sets and agricultural implements, in 2012-13. This is the highest sectoral consumption in the non-transport category. In addition to this, heavy fuel oils like furnace oil and Low-Sulphur Heavy Stock (LSHS) are also used for agricultural implements.

Fishery is a minor contributor to GHG energy emissions, contributing < 1% to the global GHG emissions (Vivekanandan et al., 2013). According to IPCC 2006 methodology, energy based emissions from fisheries sector are based on the fuel burnt in fishing fleets. The three major types of fishing crafts used in the fisheries sector are motorised, mechanised and non-motorised. According to the Marine Fisheries Census 2010, 74% of the fishing crafts are mechanised and motorised (Central Marine Fisheries Research Institute, 2010). The sudden growth of energy-intensive fishing crafts started in the 1980s when kerosene began to be used as fuel to operate the crafts. With the introduction of diesel-powered engines, the larger crafts started using diesel for fuelling.

Electricity consumed by residential, commercial and agriculture sectors are not considered as an activity data and their GHG emissions in these sectors are considered to be zero. This is because electricity emits GHG only during the generation process which is accounted for in the 'Electricity Generation' sub-sector under energy sector in 2006 IPCC methodology (Blignaut et al., 2005; IPCC, 2006).

3.2. Emission factor

In accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Tier I and Tier II approaches are used

Table 1
Emissions from existing inventories ('000 tCO_2e).

Sectors	1994[a]	2007[b]	2010[c]
Residential	43,918.00	137,838.49	84,678.38
Commercial	20,571.00	1673.18	4753.71
Agriculture and Fisheries	32,087.00	33,658.7	2933.99

[a] (MoEFCC, 2004).
[b] (MoEF, 2010b).
[c] (MoEFCC, 2015b).

Table 2
Global warming potential (GWP).

Industrial Designation or Common Name	Chemical Formula	Lifetime (years)	Radiative Efficiency (W/ m^2/ppb)	GWP for Given Time Horizon as per AR2 (100 years)
Carbon dioxide	CO_2	Up to 100 years	1.4×10^{-5}	1
Methane	CH_4	12	3.7×10^{-4}	21
Nitrous oxide	N_2O	114	3.03×10^{-3}	310

wherever country-specific emission factors are available. The emission factors for CH_4 and N_2O have been taken from the default values of IPCC 2006, whereas the emission factor for CO_2 is a mix of country-specific data and default values in IPCC 2006. Table 3 details the emission factors of the fuels used in stationary combustion in residential, commercial/institutional and agriculture/fishing categories.

3.3. Data sources

Activity data for most of the sectors were derived from different documents published by the various ministries and organisations under the Government of India as well as peer-reviewed papers and reports. The sources and reliability of each activity data are provided in Table 4.

4. Results and discussions

4.1. Sector-wise GHG emissions

The annual emissions from the four sectors have increased from 123 to 150 $MtCO_2e$, from 2005 to 2014, at a Compounded Annual Growth Rate (CAGR) of 2.23%. More than 70% of these emissions are from the residential sector, followed by agriculture/fisheries and the commercial sector. Fig. 1 shows the time series trend of GHG emissions ($MtCO_2e$) in the sectors mentioned above.

4.2. GHG emissions from residential sector

In the residential sector, the usage of high-carbon-based fuels like coke, coal, charcoal, etc., is very less as compared to other fuels like LPG and kerosene. The GHG emissions from fuelwood are similar to the emissions from LPG and kerosene in the residential sector. This is because of the high quantities of CH_4 and N_2O emissions generated from fuelwood. Studies have shown that the residential sector is a major contributor to high emissions levels in cities (Ramachandra et al., 2015). GHG gases in this sector are largely generated by the usage of fuelwood, LPG and kerosene. It can be seen from Fig. 2 that emissions from fuelwood and kerosene have reduced by around 3–4% each year, whereas emissions from LPG usage has increased by 5.32% annually over these years. Also, the per capita consumption of coal and coke in the country remained the same or increased marginally over this period. However, the population growth rate of the country was 1.4% every year from 2005 to 2014. This means that the increased emissions from coke, coal and charcoal (2.47%) can be attributed to population growth. During this period, the new entrant, PNG, started penetrating into the Indian households at a rate of 11.96%. The emission profiles show that the higher emitting fuels like kerosene, coal, charcoal and coke slowly exited the Indian residential sector and low-carbon-emitting fuels like LPG and PNG started dominating the market. The consumption of diesel in DG sets increased greatly during this period, due to the power deficit in major cities in the country. The emission from DG sets contributes 2–4% of the total emissions in the residential sector and has been observed to increase by 6% annually. Due to the shift from traditional high-carbon-emitting fuels to low-carbon-emitting fuels in the residential sector, the emissions grew at only 0.6% during the study period. Fig. 2 shows the fuel wise CO_2e emissions from the residential sector.

4.3. GHG emissions from commercial sector

The commercial sector emitted considerably less compared to the other sectors. Major emissions in the commercial sector are from the usage of High Speed Diesel Oil (HSDO) consumed in DG sets. The emissions from DG sets contribute to more than 50% of the emissions in this sector. The emissions increased from 2.6 to 5.2 $MtCO_2e$ from 2005 to 2012 and later decreased to 4.5 $MtCO_2e$ in 2014. The other major fuel used in the commercial sector is LPG which is used for cooking in hotels or catering units during social gatherings/events, etc. The usage of kerosene had increased at 14% per annum from 2005 to 2010 and then reduced at a rate of 5% from 2011 to 2014. The emissions from PNG started growing at 12%, though their quantity is negligible as compared to other fuels in the commercial sector. Overall, the emissions from the commercial sector have increased by 9.11% from 2005 to 2014. This sector contributes very less CH_4 and N_2O emissions. Fig. 3 shows the CO_2e emissions from the commercial sector.

4.4. Agriculture

Diesel consumption by tractors, agriculture implements and agriculture pump-sets contributes to 99% of the total emissions from the energy usage in the agriculture sector. The remaining emissions are contributed by the usage of LPG, furnace oil and LSHS. This sector also contributes very less CH_4 and N_2O emissions. Fig. 4 shows the CO_2e emissions from the agriculture sector.

4.5. Fisheries

Emissions from the fisheries sector started with the introduction of mechanised and motorised boats in India. The emissions from the fisheries sector increased from 3.2 $MtCO_2e$ to 5.1 $MtCO_2e$ from 2005 to 2014. Over this period, the diesel usage in the motorised and mechanised marine fishing fleets contributed 80–90% of the total emissions in the industry. The remaining emissions are from kerosene consumption in the fishing fleets. The consumption of diesel fuel increased by 6.65% annually due to a switch to energy-efficient fuels in fishing fleets, whereas the usage of less energy-efficient kerosene fuel has reduced by 3.36% between 2005 and 2014. Fig. 5 shows the CO_2e emissions from the fisheries sector.

4.6. Comparative analysis of emission estimates with INCCA and BUR

A comparative analysis of the 2007 and 2010 government inventories was performed with the author's estimates. The greenhouse gas emission estimates for 2007 was prepared by MoEFCC for Indian

Table 3
NCVs and EFs for stationary combustion of fuels.

Fuel	NCV (TJ/kt) [a]	CO_2 EF (t/TJ)	CH_4 EF (kg/TJ)	N_2O EF (kg/TJ)
Coking coal	24.2	93.6	300	1.4
Diesel	43.0	74.1	10	0.6
Charcoal	29.5	112.0	200	1.0
Kerosene	43.8	71.9	10	0.6
Fuel oil	40.4	77.4	10	0.6
PNG	48.0	56.1	5	0.1
LPG	47.3	63.1	5	0.1
LSHS	40.2[b]	73.3[c]	10	0.6
Fuelwood	15.7	0.0	300	4.0

EF, Emission Factor.
[a] (MoEF, 2010a,b).
[b] (Ramachandra et al., 2015).
[c] (Majumdar Deepanjan, 2011).

Table 4
Data sources of Activity data.

Sectors	Activity data	Reliability	Source
Residential	LPG	High	Ministry of Petroleum and Natural Gas Statistics (MoPNG, 2014, 2013, 2011, 2009)
	Fuelwood, Coke, Coal, Charcoal	Medium	National Sample Survey Office (NSSO, 2014, 2012, 2007)
	Kerosene	High	Ministry of Petroleum and Natural Gas Statistics (MoPNG, 2014, 2013, 2011, 2009)
	Natural Gas	Medium	India Energy Dashboards (NITI Aayog, 2016)
	Diesel	Low	(Nielson, 2013; ICF International, 2014)
Commercial	LPG	High	Ministry of Petroleum and Natural Gas Statistics (MoPNG, 2014, 2013, 2011, 2009)
	Kerosene	High	Ministry of Petroleum and Natural Gas Statistics (MoPNG, 2014, 2013, 2011, 2009)
	Diesel	Low	(Nielson, 2013; ICF International, 2014)
	Natural Gas	Medium	Ministry of Petroleum and Natural Gas Statistics and India Energy Dashboards (MoPNG, 2016, 2014; NITI Aayog, 2016)
Agriculture	LPG	High	Ministry of Petroleum and Natural Gas Statistics (MoPNG, 2014, 2013, 2011, 2009)
	Diesel	Medium	Ministry of Petroleum and Natural Gas Statistics, PPAC (MoPNG, 2014, 2013, 2011, 2009; Nielson, 2013)
	Furnace Oil	High	Ministry of Petroleum and Natural Gas Statistics (MoPNG, 2014, 2013, 2011, 2009)
	LSHS	High	Ministry of Petroleum and Natural Gas Statistics (MoPNG, 2014, 2013, 2011, 2009)
Fisheries	Kerosene	Low	Expert interviews, Peer-reviewed journals (Vivekanandan et al., 2013; Aswathy et al., 2013)
	Diesel	Low	Expert interviews, Peer-reviewed journals (Vivekanandan et al., 2013; Aswathy et al., 2013)

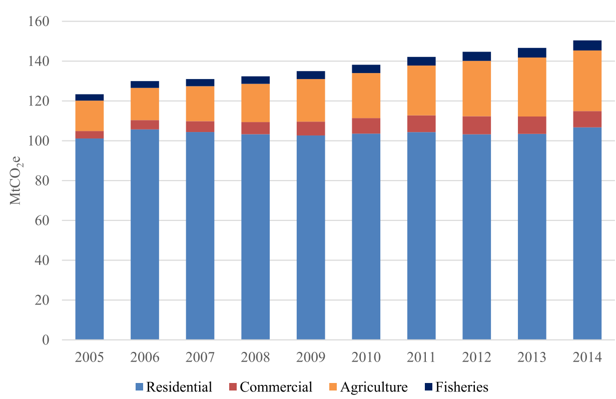

Fig. 1. GHG emissions from residential, commercial and agriculture/fisheries sectors.

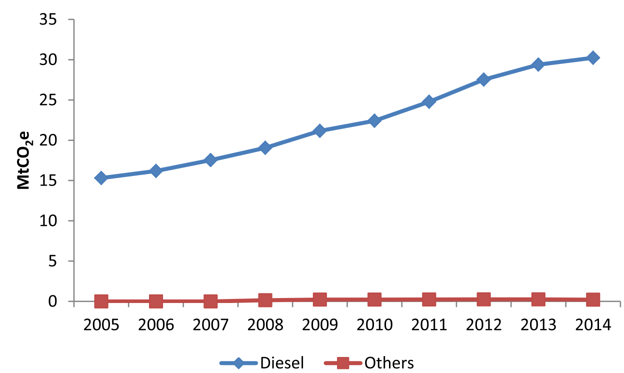

Fig. 4. CO_2e emissions from agriculture sector.

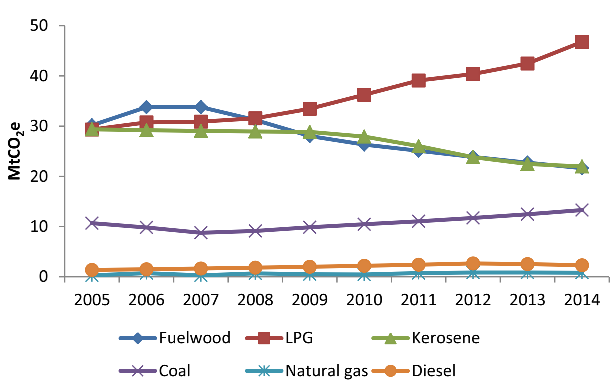

Fig. 2. CO_2e Emissions from residential sector.

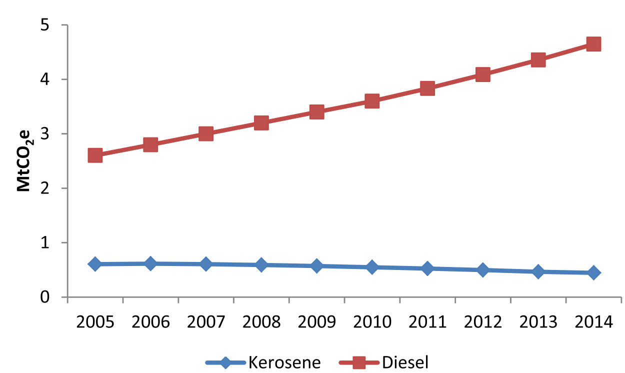

Fig. 5. CO_2e emissions from fisheries sector.

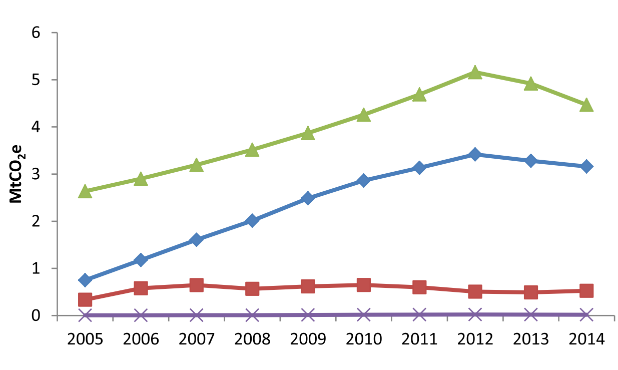

Fig. 3. CO_2e emissions from commercial sector.

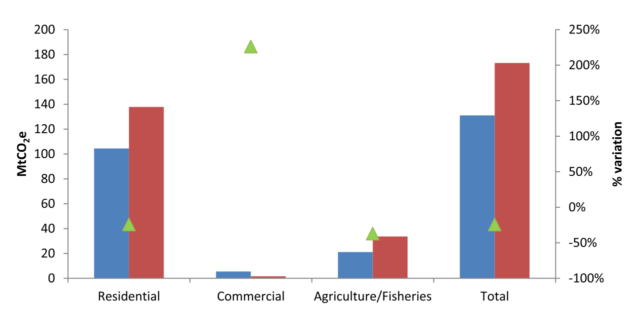

Fig. 6. Sector-wise emissions in 2007 (author's analysis and INCCA analysis).

Network for Climate Change Assessment (INCCA). It was then observed that the author's emission estimates were lower in the residential and agriculture/fisheries sectors and higher in the commercial sector as compared to the INCCA analysis. The estimates and % variation between the author's estimate and the INCCA emission estimates are shown in Fig. 6.

Due to lack of complete data, the data samples from National Sample Survey (NSS) were used to estimate the energy consumption in the residential sector which is just a representative sample for India (NSSO, 2012; NSSO, 2014). This could have led to emission estimates lower than that estimated by INCCA for 2007. Also, the INCCA inventory has not taken into consideration the emissions from captive power generation like DG sets, which led to increased emission estimates in our analysis, in the commercial sector. In case of agriculture/fisheries sector, the ratio of kerosene to diesel consumption was considered from a coastal representative state and has been applied to calculate the national inventory.

The Biennial Update Report (BUR) prepared for 2010 showed a sharp decline in emissions of approximately 39% and 91% in residential and agriculture/fisheries sectors, respectively, and a steep growth rate of 184% in the commercial sector as compared to the 2007 inventory. This contradicts the World Bank database which shows that the population in India is growing annually at a rate of 1.5% leading to an increase in demand for energy. According to NSS reports, the per capita coal and coke consumption in the country remained the same/increased marginally during 2007-12. Hence, the emission from coke has increased by 22% in 3 years. In addition to this, the emissions from LPG and PNG consumption have increased by 5% and 22%, respectively. Due to the frequent power cuts faced in major parts of the country, the number of DGs in residential sectors has increased over the years. There has been an approximately 10% increase in emissions in the residential sector due to use of diesel in DG sets. All these parameters clearly show that the emissions from the residential sector will increase over the years.

Similarly, in the agriculture/fisheries sector, the 2010 emissions have reduced by one-tenth of the 2007 emission estimates. However, there has not been any technology breakthrough in these sectors for a sudden reduction in emissions. Moreover, the share of diesel consumed in the agriculture sector has only increased from 11.9% to 13% from 2008 to 09 to 2012-13 (Anand, 2012; Nielson, 2013). Thus, there is very little chance of emissions to have reduced from 2007 to 2010 in the agriculture/fisheries as justified earlier. This clearly suggests that the difference in methodology used by the two inventories has resulted in wide variations in emissions.

The author has estimated the 2010 emissions from the residential, commercial and agriculture/fisheries sectors to be as 104, 8 and 27 $MtCO_2e$, respectively. The estimates and % variation between the author's estimate and the BUR inventory are shown in Fig. 7.

The emission estimates provided in INCCA and BUR reports are not detailed at the activity level for each sector. Non-availability of time series data in IPCC friendly format, the mismatch in sectoral data published across different documents and inconsistency in top-down and bottom-up datasets were some of the data gaps and constraints that were faced during preparation of the 2010 emission inventory. Hence, it is not clear whether all the sectoral activities were included in the emission calculation. In addition to this, it is not clear as to how the INCCA and BUR estimates were calculated for the calendar year. This could have led to the variations in the emission estimates reported by the author.

5. Uncertainties

The emission estimates calculated in this study are based on source activity collected from various reports published by the Government of India. The data on fuelwood, kerosene and coal consumption in the NSS reports are expressed in terms of kg used per capita per month. The fuel consumption is converted to absolute values by the estimated urban and rural populations of the country for each year. This could have led to the author's emission estimates to be lower than INCCA's estimates for the residential sector in 2007. NSS data is not a completely reliable data as compared to Census data as the sample size of the data considered in NSS surveys is not highly representative at the national level. At the same time, NSS surveys of the same theme are not conducted at frequent time intervals using similar questionnaire pattern leading to increased data gaps with respect to time (Bairagya, 2016).

Data on the usage of diesel in DG sets were available only for one year in the public domain. They have been extrapolated for all the years in the study period assuming a constant growth rate. As discussed in section 3.1, DG sets of capacity less than 75 kW are assumed to be used in the residential sector and capacities between 75 and 800riy kW are used in the commercial sector. Since the exact growth rate and sharing of DG capacities are not known, this could have led to a higher estimation of the emissions from the commercial sector as compared to MoEFCC estimates in 2007 and 2010. The emissions from PNG utilised in the residential sector, and diesel and kerosene used in the fisheries sector have been calculated using several assumptions as discussed in earlier sections.

The quality of data depends on the reliability of the source of the data. The activity data, emission factors and assumptions made were collected from reports published by government departments, peer-reviewed and published academic research works and information disseminated by technology suppliers. The data were validated from other publicly available sources. Owing to limitations in availability of selected fuels like charcoal and kerosene data in the residential sector, interpolation method was applied to bridge identified gaps. These data points are validated with expert's opinion.

To understand the effect of errors in the activity data, propagation of error method was used to calculate uncertainty. Activity data was assumed to be of normal distribution and the margin of error (or uncertainty) was calculated at 95% confidence interval. The fuel-wise uncertainties for the combined activity data of residential, commercial and agriculture/fisheries sectors are provided in Table 5. The activity data will be represented as mean value ± margin of error.

Major fuels like fuelwood LPG, kerosene and diesel shows an uncertainty less than 15%.

6. Conclusions

Considering the inconsistencies in the activity data obtained from different sources, this study focussed on generating the time series emission estimates by following a consistent methodology. India being the second most populous country in the world, great importance has to be given to the emissions from the studied sectors, especially the residential sector. The study indicates that the emissions from the residential sector have increased from 101 to 107 $MtCO_2e$ from 2005 to 2014. Similarly, the emissions from the commercial sector increased from 4 to 8 $MtCO_2e$ during the same time period. Accurate time series

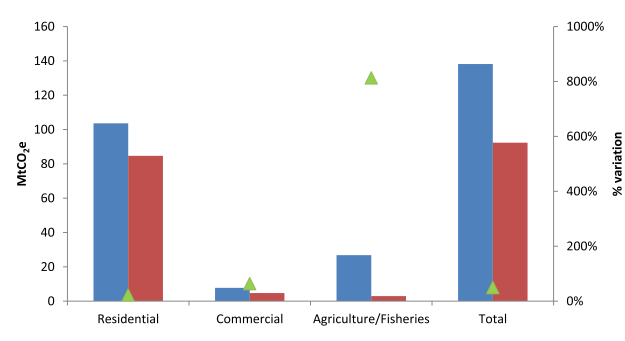

Fig. 7. Sector-wise emissions in 2010 (author's analysis and BUR analysis).

Table 5
Fuel wise Uncertainties.

Fuel	Unit	Value
Fuelwood	000 tonnes	234080 ± 3303
LPG	000 tonnes	12867 ± 1394
Kerosene	000 tonnes	8797 ± 595
Coal	000 tonnes	4126 ± 397
Charcoal	000 tonnes	205 ± 49
Diesel	000 tonnes	9960 ± 1425
Furnace Oil	000 tonnes	46 ± 31
LSHS	000 tonnes	0.38 ± 0.8
Natural gas	BCM	2.3 ± 0.57

data are useful tools to help the policymakers come up with suitable mitigation actions and also to verify the appropriateness of existing or newly implemented strategies. A slow growth of emissions in the residential sector might be due to the implementation of energy-efficient technologies for cooking and lighting. However, the emissions from the commercial sector seem to be increasing due to the increased usage of DG sets in the sector.

With a view to reducing dependence from intensive fossil fuel based cooking and lighting, Government of India had come up with several schemes like Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY), Remote Village Electrification Pratyaksh Hanstantarit Labh (PAHAL) Scheme, Pradhan Mantri Ujjwala Yojana (PMUY). But it is very evident from the results of the study that usage of coal, coke and charcoal has not yet reduced in the residential sector. In addition to that, diesel consumption in the residential and commercial sector has grown at an alarming rate from 2005 to 2014. Usage of efficient cook stoves and less polluting fuels like PNG could be incentivised and promoted among the residential and commercial sector. These fuels help in reducing indoor air pollution, which has been a major cause of mortality and morbidity, particularly in rural India. The 'Power for All' scheme could help in reducing the emissions caused by diesel generator sets in residential households and commercial establishments. Policies on fossil free capacity addition should be framed more effectively to reduce the electricity shortages in the country, thereby reducing the dependence of diesel in captive power generation. Development of GHG inventories will help in framing timely policies for the right sector which could help in achieving India's NDC target.

The accuracy of estimation of GHG emissions can be further improved by climbing up the tier ladder of emission factor. Due to inadequate information available on calculating the Tier III emission factors, the study focussed on Tier I and Tier II emission factors. There is a further scope of research to refine the GHG inventory using Tier III emission factors and refined sectoral activity data. Countries should start reporting activity data in line with the IPCC formats which will help in creating a robust GHG emission inventory.

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